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Optical parameters of the nonisothermal Uranus's and Neptune's atmospheres

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Abstract.

A method of the calculation of optical parameters of the nonisothermal giant planet atmospheres was developed using detailed intensity data of Raman scattering. We have used the model of Morozhenko (A.V. Morozhenko, 1997) as a baseline. In such a way, using observational data of Uranus and Neptune (E.Karkoschka, 1994), the spectral values of ratio of optical depth components: aerosol and gas components τ_a/τ_R, absorbing and scattering components τ_κ/τ_R, and also single scattering albedo of aerosol component corrected for Raman scattering ω' were obtained (where τ_a, τ_R are aerosol and gas components, and τ_κ is absorbing components of effective optical depths of the formation of diffusely reflected irradiation). The averaged value of ratio τ_a/τ_R is 0.96 but it slowly decreases in the spectral range of 350-450nm for Uranus and τ_a/τ_R is 1.35 for Neptune.

1. Introduction

The atmospheres of Uranus and Neptune are known to be composed predominantly of molecular hydrogen. Since there is so much H_2 in the atmospheres of outer planets and H_2 has a reasonably strong Raman spectrum, it is very important to attempt to understand the physics of planetary Raman scattering.

Raman scattering is the incoherent non-resonance scattering of photons by a molecule. During molecular scattering process, the photon may loose energy according to certain molecular transitions. If the incident solar photon of frequency ν_0 is scattered, it will emerge at frequency $\nu_0 \pm \triangle\nu$, where $\triangle\nu$ is the frequency of the Raman transition of the molecule.

In recent years the observational data of detailed intensity of Raman scattering in the giant planet spectra was proposed to use to determine the relative contribution of the aerosol component of atmosphere. In such a way, we can determine the values of aerosol to gas ratio of optical depth components τ_a/τ_R, and absorbing to scattering ratio τ_κ/τ_R (M.S.Dementiev,1992; A.V.Morozhenko, 1997). In these papers, the model of atmosphere was taken to be isothermal, while the real giant planet atmospheres have complex temperature profiles (G.F.Lindal, et al., 1987; G.F.Lindal, et al., 1990). The relative number of hydrogen molecules in the ortho- and para- state depends on the depth in the nonisothermal atmosphere, while it doesn't depend on the depth in the isothermal

one. So, the detailed intensity of Raman scattering will depend on the effective optical depth of the formation of diffusely reflected irradiation. The method of accounting of the real temperature profile in computing of Raman scattering effects was developed by Morozhenko and Kostogryz (A.V.Morozhenko and N.Kostogryz, 2005).

This paper presents a method of computation of optical parameters of the Uranus's and Neptune's atmospheres such as τ_a/τ_R and τ_κ/τ_R considering detailed intensity of Raman scattering and using observational data of Uranus's and Neptune's atmospheres (E.Karkoschka, 1994) and experimental temperature profiles (G.F.Lindal, et al., 1987; G.F.Lindal, et al., 1990).

Section 2 contains reviews of the model of atmosphere. Section 3 is devoted to the method of computation and sections 4 and 5 describe results of computation and some conclusions of this work.

2. Model of atmosphere

As reliable information about vertical structure is lacking, especially about aerosol component of atmosphere, we will use the model of homogeneous semi-infinite gas-aerosol layer. We take into account that gas components of atmosphere are hydrogen(85%) and helium(15%), and also we consider nonisothermal atmospheres of Uranus and Neptune using experimental temperature profiles (G.F.Lindal, et al., 1987; G.F.Lindal, et al., 1990).

Raman scattering is considered for the four major hydrogen transitions, the rotational S(0), S(1) and O(2) and the vibrational $Q_1(1)$ transitions, which produce significant Raman ghosts. Raman shifts and cross sections at 400nm of several transitions of molecules of interest in planetary atmospheres were taken from Cochran and Trafton(W.D.Cochran and L.M.Trafton, 1978).

At the temperatures of planetary atmospheres, most of the molecules are in the lower rotational levels of the ground vibrational state. Therefore the Stocks component of the Raman scattering will dominate. The molecule will absorb energy and the photon will emerge at lower frequency or longer wavelength than it entered.

The estimation of the spectral values of single scattering albedo was obtained via comparison of observational data of geometric albedo (E.Karkoschka, 1994) and theoretical computed for homogeneous semi-infinite layer with a Rayleigh scattering indecatrix by Ovsak(A.V.Morozhenko, 2004).

The values of effective pressure on that intensity of diffuse reflected radiation is forming were taken from Morozhenko's paper (A.V.Morozhenko, 2006)

3. Method of computation

To take into account Raman scattering effects equation of single scattering albedo from Pollack was used (J.B.Pollack et al., 1986). While Pollack considers only photons which are shifted to λ_0 due to Raman scattering, we propose more correct expression for single scattering albedo, which account still photons which are shifted from λ_0 due to Raman scattering.

$$\omega = \frac{\tau_a/\tau_R + D}{1 + \tau_a/\tau_R + \tau_\kappa/\tau_R} \tag{1}$$

$$D = 1 + 0.85 * [((N_0\tau_{S(0)} + N_2\tau_{O(2)})f_{\lambda_1} + N_1\tau_{S(1)}f_{\lambda_2} + \tau_{Q_1(1)}f_{\lambda_3})/f_{\lambda_0}\tau_R] - A \tag{2}$$

$$A = 0.85 * (N_0\tau_{S(0)} + N_2\tau_{O(2)} + N_1\tau_{S(1)} + \tau_{Q_1(1)})/\tau_R \tag{3}$$

where $f_{\lambda_1}, f_{\lambda_2}, f_{\lambda_3}$ are spectral values of the energy in Solar spectrum on the wavelength, from which rotation $(S(0), O(2), S(1))$ and vibration $(Q_1(1))$ Stocks transition of Raman scattering carries the sun photon on wavelength λ_0 accordingly; $\tau_{S(0)}, \tau_{O(2)}, \tau_{S(1)}$ and $\tau_{Q_1(1)}$ are optical depths of the Raman scattering of corresponding transition.

The amount of hydrogen molecules in ortho- and para- state described as

$$N = 3(2j+1)\exp -B * j(j+1)\frac{hc}{kT}; j = 1, 3, 5 \ldots \tag{4}$$

$$N = (2j+1)\exp -B * j(j+1)\frac{hc}{kT}; j = 0, 2, 4 \ldots \tag{5}$$

where B is rotation constant, which for hydrogen molecule is equal $60cm^{-1}$, j is quantum number, h is Planck constant, c is speed of light, k is Boltzman constant, T is temperature (in Kelvin).

Solar spectrum (L.Delbouille, et al., 1973) which reduced to 1-nm resolution was used in our investigations.

It was the first step of our code which was described in details by Morozhenko and Kostogryz (A.V. Morozhenko, N. Kostogryz, 2005)

The estimation of parameter D was obtained using (2) and the spectral values of single scattering albedo were obtained via comparison of observational data of geometric albedo (E.Karkoschka, 1994) and computed for homogeneous semi-infinitive layer with Rayleigh scattering indecatrix by Ovsak (A.V.Morozhenko, 2004). Then we approximate that (τ_a/τ_R) is constant every 10 nm from 350-450 nm. Using min-square method, we obtained such a value of (τ_κ/τ_S) where $\tau_\kappa/\tau_S = (\tau_\kappa/\tau_R)/(1 + \tau_a/\tau_R)$ has minimum dispersion. At that, (τ_a/τ_R) can have values from 0 to 3 with 0.03 resolution. After that, we average all values of (τ_a/τ_R) over spectral interval 350-450 nm on which methane bands are practically absent and find spectral dependence of (τ_κ/τ_S).

After determination of (τ_a/τ_R), single scattering albedo (ω') was corrected for Raman Scattering using such a formula:

$$1/\omega' = (D + \tau_a/\tau_R)/((1 + \tau_a/\tau_R) * \omega) \tag{6}$$

4. Results and discussions

A method of accounting complex temperature profile for determine such parameters of atmosphere as (τ_a/τ_R), (τ_κ/τ_R) and (τ_κ/τ_S) was developed and the

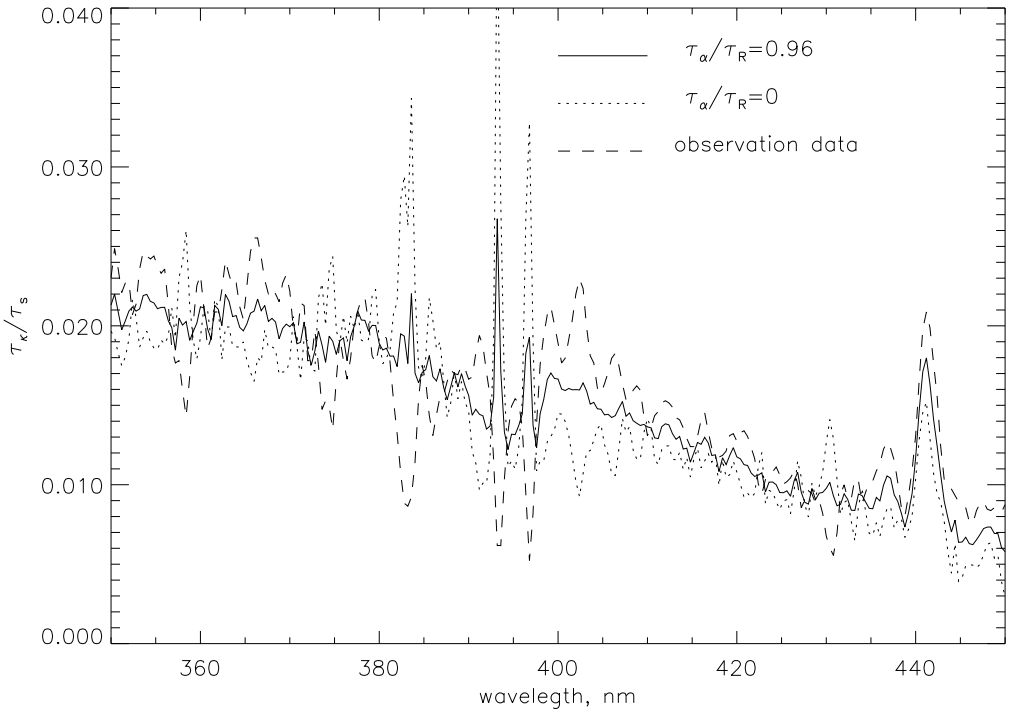

Figure 1. Spectral dependence of (τ_κ/τ_S) for Uranus. Observational data denoted as dotted line, points are for gas atmosphere $(\tau_a/\tau_R = 0)$, and solid line is for nonisothermal gas-aerosol atmosphere $(\tau_a/\tau_R = 0.96)$

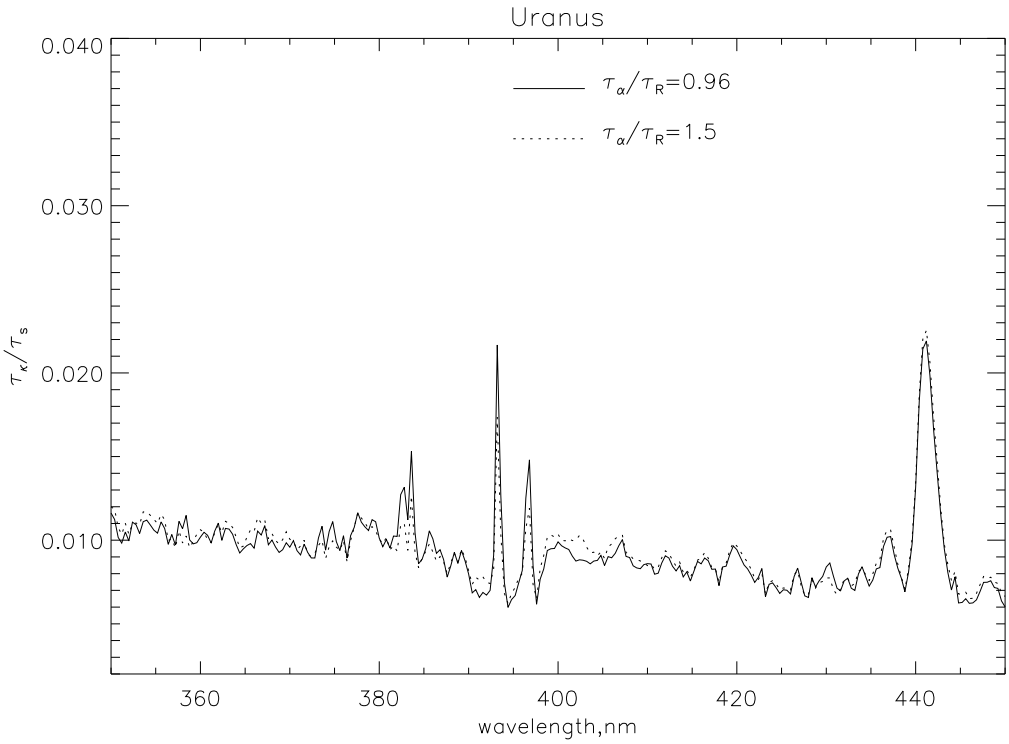

Figure 2. Spectral dependence of (τ_κ/τ_S) for isothermal(dotted line) and nonisothermal(solid line) Uranus atmosphere

averaged value of ratio of the optical depth component: aerosol and gas component $(\tau_a/\tau_R = 0.96)$ for Uranus, and $(\tau_a/\tau_R = 1.35)$ for Neptune were obtained and the spectral dependence of (τ_κ/τ_S) was also obtained.

In fig.1 comparison of spectral dependence of (τ_κ/τ_S) for observational data of Uranus which determined as $\tau_\kappa/\tau_S = 1/\omega - 1$, for gas atmosphere $(\tau_a/\tau_R = 0)$, and for nonisothermal gas-aerosol atmosphere $(\tau_a/\tau_R = 0.96)$ is depicted. It is shown, that the values of (τ_κ/τ_S) have minimum dispersion at $(\tau_a/\tau_R = 0.96)$. So, we can obtained (τ_κ/τ_S) corrected for Raman scattering.

Morozhenko and Kostogryz(A.V.Morozhenko and N.Kostogryz, 2005) showed that ignoring of real temperature profile could lead to large errors in determination of (τ_a/τ_R), (τ_κ/τ_R) and (τ_κ/τ_S). In this paper we check this result using real values of these parameters. For this purpose we determined all these parameters for isothermal atmosphere with effective temperature $T = 57.1K$ and such value $(\tau_a/\tau_R = 1.5)$(fig.2) was obtained.

It is known, that one of the Raman scattering effects in the Uranus's and Neptune's atmospheres is decreasing of geometric albedo and single scattering albedo in the UV spectra that can be discussed as pseudo-absorption in continuum. Using this method, we computed values of single scattering albedo corrected for Raman scattering and compared them with observed ones (fig.3).

The values of aerosol and gas ratio of optical depth components were obtained for Uranus $(\tau_a/\tau_R = 0.96)$ and for Neptune $(\tau_a/\tau_R = 1.35)$, and compar-

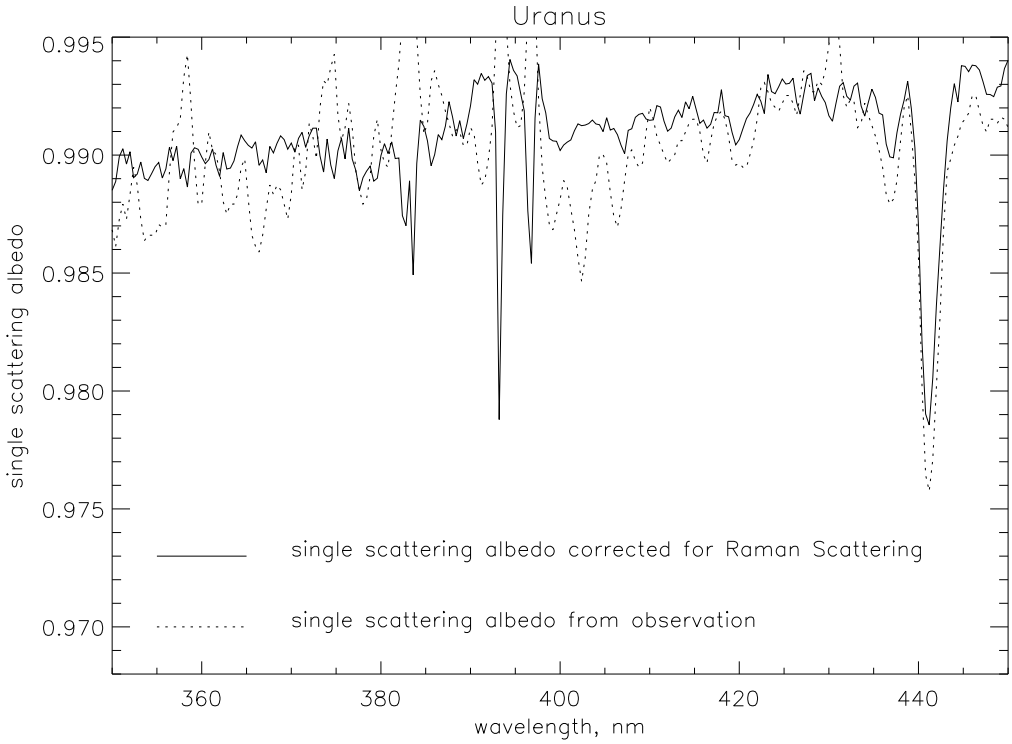

Figure 3. Spectral dependence of single scattering albedo for Uranus. Observational data denoted as dotted line, and solid line is single scattering albedo corrected for Raman scattering

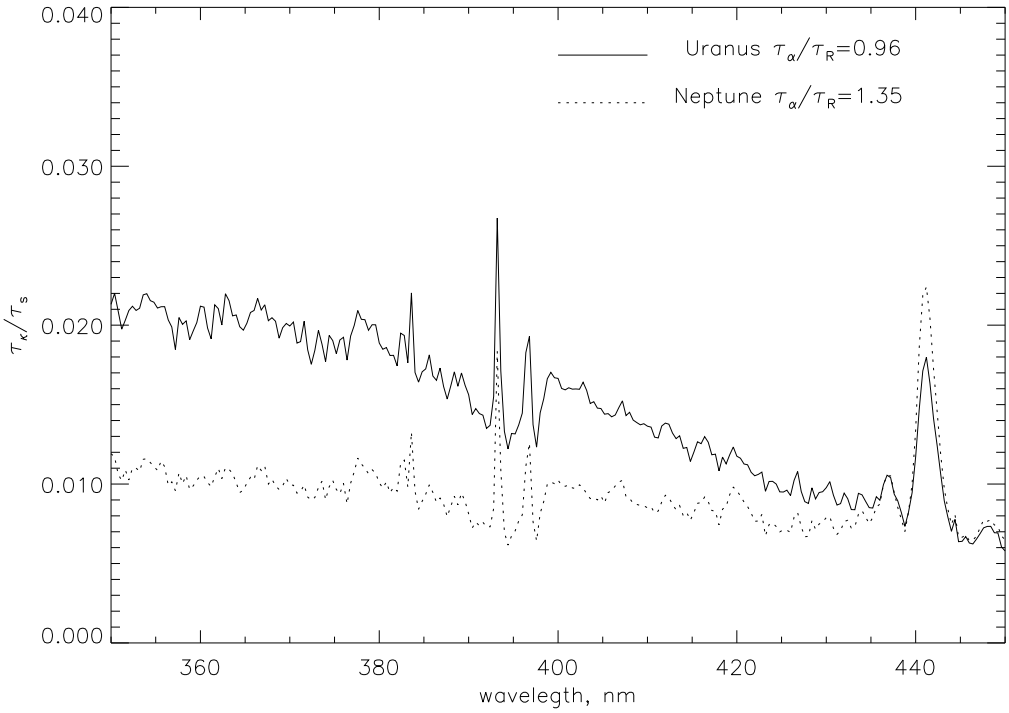

Figure 4. Spectral dependence of (τ_κ/τ_S) for Uranus(firm line) and Neptune(dotted line).

ison of these data shows that the amount of aerosol in Neptune is larger than in Uranus(fig.4).

5. Conclusion

In this paper we determined the values of aerosol to gas ratio of optical depth component for Uranus ($\tau_a/\tau_R = 0.96$) and for Neptune ($\tau_a/\tau_R = 1.35$), and spectral dependence of absorbing to scattering ratio τ_κ/τ_S.

We confirmed that ignoring of real temperature profile leads to 50 % errors in determination of (τ_a/τ_R).

Real spectral values of single scattering albedo corrected for Raman scattering, were obtained for spectral region 350-450 nm.

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